

OMV MISSION SIMULATOR

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ABSTRACT

The Orbital Maneuvering Vehicle (OMV) will be remotely piloted during rendezvous, docking, or proximity operations with target spacecraft from a ground control console (GCC). This paper describes the real-time mission simulator and graphics being used to design a console pilot-machine interface.

A real-time orbital dynamics simulator drives the visual displays. The dynamics simulator includes a J2 oblate earth gravity model and a generalized 1962 rotating atmospheric and drag model. The simulator also provides a variable-length communication delay to represent use of the Tracking and Data Relay Satellite System (TDRSS) and NASA Communications (NASCOM).

Input parameter files determine the graphics displays. This feature allows rapid prototyping since displays can be easily modified from pilot recommendations. Different subsets of OMV telemetry data can be shown to determine the information necessary for pilot operations.

A series of pilot reviews are being held to determine an effective pilot-machine interface. Pilots fly missions with nominal to 3-sigma dispersions in translational or rotational axes. Console dimensions, switch type and layout, hand controllers, and graphic interfaces are evaluated by the pilots and the GCC simulator is modified for subsequent runs. Initial results indicate a pilot preference for analog versus digital displays and for two 3-degree-of-freedom hand controllers.

INTRODUCTION

The OMV is designed as a reusable unmanned spacecraft. Initially deployed from the space shuttle, it is capable of staying in orbit for months while receiving periodic on-orbit maintenance and refueling. The

OMV is used to deliver, retrieve, reboost, or maneuver satellites between the shuttle or space station and a specific orbit.

The OMV flies autonomously to within 1000 feet of a target spacecraft. A pilot then remotely controls the OMV in rendezvous, docking, or proximity operations. The OMV will be operated by NASA personnel from a ground control console (GCC) located at the Johnson Space Center.

The GCC sends pilot commands to the OMV via NASA Communications (NASCOM) and two Tracking and Data Relay Satellites (TDRS). The OMV downlink transmissions consist of telemetry and two video camera transmissions. The communications link can transmit up to 32 kilobits/second of telemetry and 1 megabit/second of compressed video signal. The communications link has an approximate 3-second round-trip delay time.

The OMV docks with the target spacecraft using either the remote manipulator system (RMS) grapple docking mechanism (RGDM) or a three-point docking mechanism (TPDM) for those spacecraft that have a flight support system (FSS) interface.

The OMV prime contractor, under NASA Marshall Space Flight Center, is TRW. The OMV is scheduled for deployment in November 1993. Its potential first mission is in conjunction with the Waves in Space Plasma (WISP) project.

OMV flight operations will be conducted from either of two identical GCCs. A GCC provides pilot control of the OMV during all flight operation phases. Each GCC consists of switches, hand controllers, two terminals and keyboards, data processing equipment, and two monitors displaying information from the on-board docking and pan/tilt/zoom (PTZ) video cameras. The pilot manipulates hand controllers for OMV maneuvers and utilizes switches for OMV or console commands.

The GCC must provide a pilot-machine interface that gives adequate information to avoid information overload, and minimizes pilot errors. TRW was given the task of building a prototype GCC (PGCC) to simulate man-in-the-loop, real-time remote OMV teleoperations. The PGCC is the tool used to establish the console pilot-machine interface.

SIMULATOR OVERVIEW

Simulator Models

The PGCC was developed as a representative operational pilot station used for preliminary design evaluations and crew reviews. The OMV program concluded that to evaluate a pilot-machine interface fully, it was necessary to simulate a dynamic docking environment which integrates flight telemetry with hand-eye coordination. Space environment and OMV models are included in the simulation.

The simulator dynamically models the space environment. The environment models include a J2 oblate earth gravity model and a generalized 1962 rotating atmospheric density and velocity model. A drag model is based on a cylindrical approximation for the OMV and target bodies.

Each body is characterized by 6-degree-of-freedom (DOF) equations of motion including effects of position, velocity, attitude, translational and rotational rates, moments of inertia, centers of mass, and gravity gradient torques. Each target satellite is in free drift and has no control system. Only the OMV has thrusters and a flight control system.

Mission date and time parameters position the sun, moon, and earth in the simulator reference frame. Other mission parameters determine orbit position and velocities. Positions of the OMV during the simulation determine sun occlusion, camera sun intrusion, and communication zones of exclusion. They also affect lighting conditions and shading. Without these real-world conditions, valid data cannot be taken.

The simulator models several OMV subsystems. These include the fuel system, radar, and two video cameras. For example, the pilot may select either a hydrazine or GN₂ thruster system during flight. Each alternative has its own fuel tanks and rates of consumption. The hydrazine tanks are manifolded while the GN₂ tanks are independent.

Each fuel system has its own set of thrusters. Input parameter files determine the location, force vector, and impulse moment of each thruster. A particular thruster is rendered useless when the fuel tank feeding that thruster

is empty. Deviation in thruster force is modeled by varying the force vectors in a parameter file. Simulator logic is used to model the less efficient first few microseconds of burn. A thruster pulse size, initialized by an input parameter, determines the minimum burn allowed. Individual thrusters can be failed on or off. If a thruster is failed off, no force or fuel is spent. However, if a thruster fails on, fuel will be burned and corresponding impulse moments will occur.

Pilots maneuver the OMV by commanding thruster burns in one or more axes. The simulated on-board computer receives the axis thrust commands and uses a jet select table to compute thruster burn times. The simulator provides two jet select tables. The real OMV utilizes identical jet select information which is uplinked to the vehicle during preflight checkout.

The simulator also models the OMV radar subsystem. A pointing vector from the radar mount to the target is computed. This vector takes into account the OMV position, gimbal limits, and radar field of view. The simulator computes the azimuth, elevation, azimuth rate, and elevation rate from the pointing vector. The radar also models the radar-to-target surface range and range rate. Radar noise and bias are introduced into the range and range rate data for greater realism. The models also provide maximum and minimum radar cutoff points at selectable distances.

The simulator models the docking (boresight) and PTZ cameras. They both produce black and white video. The pilot operates either a joystick or switches on the PGCC console to tilt, pan, or zoom the PTZ camera to a commanded position with corresponding slew rates.

Each camera has a 30-degree half-angle field of view. Gimbal stops limit the PTZ camera range of motion. Each camera is equipped with a sensor to detect sun brightness. If sun intrusion should occur, the shutter of the camera will close, blinding that camera.

Contact detection and limited dynamics are modeled in the simulator. Since modeling full contact dynamics between all surfaces of the OMV and its target is impractical without additional computing power, the simulator detects contact only between the open or closed TPDM latches and target trunnions. The simulator computes contact dynamics with a method of "soft constraints." This technique allows solids to penetrate each other at the point of contact. The algorithm then computes the restoring normal and tangential forces based on the depth of penetration. Damping forces also may be added. In addition, sliding (Coulomb) and viscous

friction may be applied. Linear and angular momentum is conserved upon contact for complete 6-DOF motion.

The OMV model contains a flight control system. The system uses the earth centered inertial (ECI) or local-vertical local-horizontal (LVLH) reference frames. A three-axis linear control law fires thrusters if either attitude or attitude rates exceed a selectable deadband. Attitude or rate hold is disabled for an axis if a pilot commands a maneuver in that axis. In addition, an automatic attitude maneuver capability is built into the simulator. The simulator rotates the OMV by firing thrusters to the desired attitude commanded by the pilot.

The OMV uses two high-gain antennas (HGA) to communicate with the TDRSS spacecraft. The simulator maintains a pointing vector from each HGA to each TDRS. Communication zones of exclusion are based on the orbit, ECI satellite positions and velocities, earth occultation, and HGA gimbal limits.

Simulator Interfaces and Architecture

The simulator provides several interfaces in addition to the pilot-machine interface. The simulator operator has a telemetry and data display on a side terminal. The operator can introduce anomalies from either this terminal or from an event file. The event file, read in at initialization, is a list of commands and events that occur at some specified time into the simulation. The operator also receives history and contact report files for post-simulation analysis. The history file contains all OMV and target state vector information, switch inputs, and environment information. The contact report file contains time-stamped contact information.

Nearly all simulator data is initialized by input parameter files. These files determine values such as fuel and thruster characteristics, orbit position, environment data, mass properties, and size of the OMV and target. They also initialize such other data as the number of targets, placement of the video camera, radar characteristics and all simulator control information.

Orbit characteristics determine initial orbit placement and rates. This data can be specified in osculating mean of 1950 (OM50), rectangular mean of 1950 (RM50), inertial mean of launch date (IMLD), or target relative reference frames. State vector integration and derivatives are computed using quaternions. Forces and accelerations due to gravity, torques, and thrusters are computed using the Adams-Moulton integrator.

The simulator maintains its own time with software interrupts. Each major subsection is given a constant delta time each cycle to perform its tasks. For example, the input subsection reads the joysticks and switches every 50 milliseconds. The on-board computer (OBC) subsystems are executed every 250 milliseconds and graphic displays are updated every 200 milliseconds. This approach simplifies the software architecture, eliminating separate processes and semaphores. However, one slow subsection can degrade the entire simulation.

The simulator hardware consists of a MicroVAX 3600, Chromatics CX2000 with frame grabber and a 24-bit z-buffer. The CX2000 drives two 1280 x 1024 pixel 19-inch monitors. A Q-bus Direct Memory Access (DMA) connects the MicroVAX with the CX2000. The simulator drives two pilot consoles, each containing hand controllers and up to 48 switches. The simulator is built from approximately 17,000 lines of FORTRAN.

PILOT-MACHINE INTERFACE

Interface Description

The main PGCC task is to define a pilot-machine interface: the physical console and graphic displays. The console interface consists of console dimensions, hand controllers, and placement, function, and choice of switches. The console ergonomics are designed to accommodate the 95th percentile man and 5th percentile woman (Figure 1).

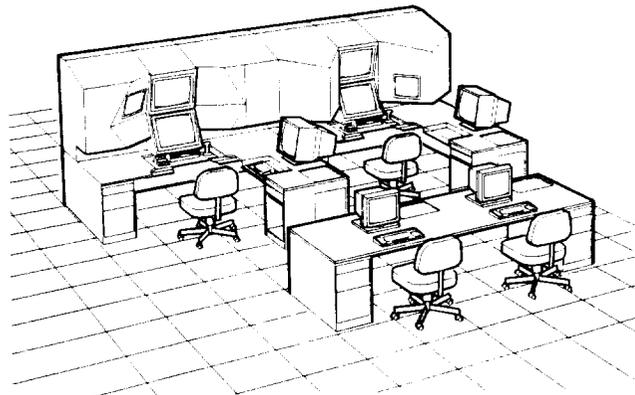


Figure 1. Prototype Ground Control Console

The selection, placement, and style of telemetry and video data form the second part of the pilot interface. A language was created to express overlay characteristics and to allow easy reconfiguration. Input parameter files, written in this language, define the color, placement,

style, etc. of each overlay. In this way, per-simulation customization can take place. In addition, alternate styles of display, graphic or text, can both be accommodated (Table I). Merely changing the input files drastically alters the "look and feel" of the pilot-machine interface. Figure 2 shows a current set of piloting overlays.

Table I. Overlay Definition File

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*
* TPDM Docking Overlay
*
BEGIN_ICON NEAR_FIELD
OVERLAY 0
OFFSET 100.0 73.242
SCALE 1.0 1.0 1.0
ROT 0.0
SUB_ICON
  COLOR WHITE
  OFFSET 0.0 0.0
*   Vertical Ranging Marks
*   10 feet out
  LINE -4.736 2.0 -4.736 -2.0
  LINE 4.736 2.0 4.736 -2.0
*   3 feet out
  LINE -15.787 2.0 -15.787 -2.0
  LINE 15.787 2.0 15.787 -2.0
*   Minimum docking range
  LINE -21.714 2.0 -21.714 -2.0
  LINE 21.714 2.0 21.714 -2.0
END_SUB_ICON
END_ICON
*
BEGIN_ICON DOWN_THRUST
OVERLAY 1
SUB_ICON
  OFFSET 3.5 1.0
  ROT 270.0
  SCALE 1.0 1.0 1.0
  FILLED
  COLOR CYAN
  ARROW
  ARC 90.0
END_SUB_ICON
SUB_TEXT
  HEIGHT 2
  EXPAND 1.0
  RIGHT
  STRING Rate:
END_SUB_TEXT
END_ICON

```

DOCKING INTERFACE

The pilot operates hand controllers and switches to guide the OMV to a dock with the target vehicle. The OMV is equipped with one of two types of grappling mechanisms depending on the target vehicle interface. Two standard mechanisms include the RGDM or the TPDM. The current simulator configuration models the TPDM with the Hubble Space Telescope. After the pilot maneuvers the OMV within the docking envelope, the three TPDM latches

can be independently closed, ensnaring the trunnions mounted on the aft of the Space Telescope.

The pilot uses the docking target located on the back face of the target satellite as a guide when docking. The target, in relation to the docking overlay, gives the pilot relative translation and rotation information. When the docking target fills the docking overlay, the target trunnions are within the grapple capture envelope.

Each TPDM latch mechanism is equipped with two sensor beams. When the trunnion breaks a sensor beam, the corresponding grapple beam overlay changes color. Using the overlays and video, the pilot can accurately determine the position and attitude of the target relative to the OMV.

Attitude errors discernible from the Space Telescope docking target are larger than the TPDM will accommodate. Therefore, the docking overlay is built to give the pilot information on maximum attitude and translational docking allowances. With this overlay, the pilot can back out, if necessary, to realign the OMV with the target for a safer dock. If the docking target should exceed the overlay, the pilot can expect the latches to contact the trunnions. The overlay provides the allowances at the minimum docking range (when the trunnion are just within the docking envelope) and at the point when the trunnions are centered over the second (inside) beam.

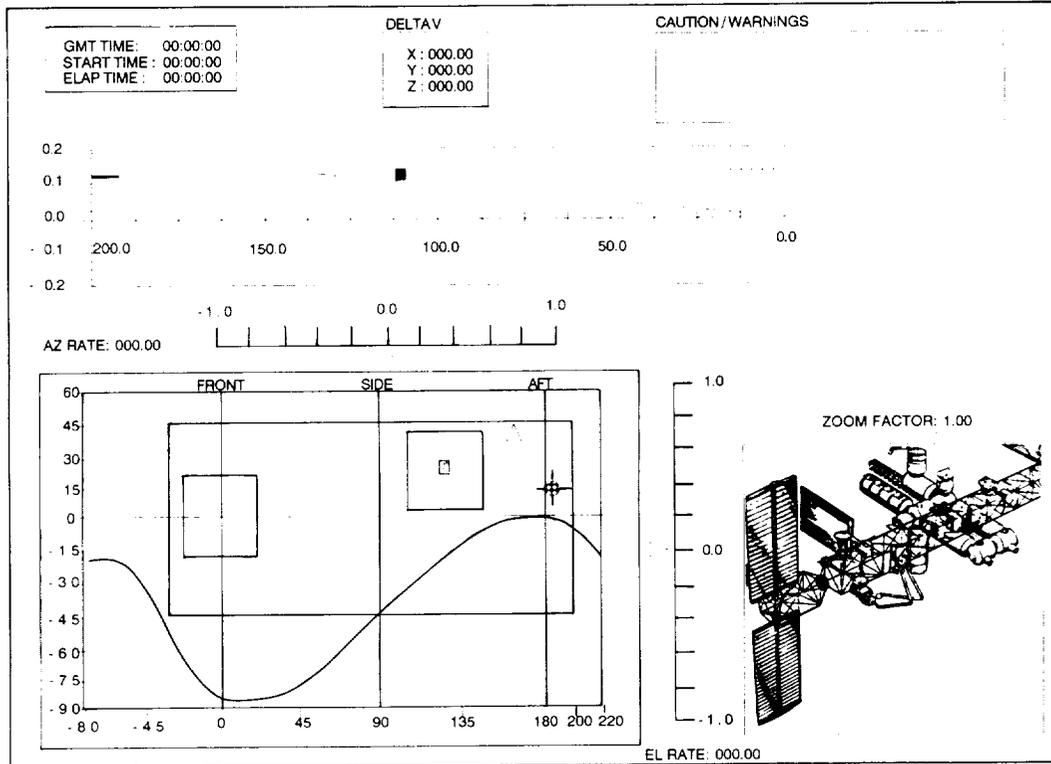
Astronaut comments indicate that range and range rate information is especially important within the radar cutoff point. Since acceptable latch closure rates are 0.1 foot/second along any axis and 0.5 foot/second about any axis, it is important the pilot get an accurate "feel" for the OMV's closing rate. Therefore, ranging aids were built into the docking overlay.

PILOT REVIEW

Approach

The first in a series of simulator reviews was held in August 1988. Thirteen people from TRW, Johnson Space Center, and Marshall Space Flight Center, including two astronauts, were available as pilots. The pilots ran through a sequence of training procedures to familiarize themselves with switch layouts, OMV thruster sensitivity, docking procedures, and overlays. After being "qualified," each pilot ran a set of simulations emulating various mission phases. Initial conditions ranged from nominal to 3-sigma cases in translational or rotational rates. Overlays were explained prior to each training procedure. Piloting tips were

Upper Monitor



Lower Monitor

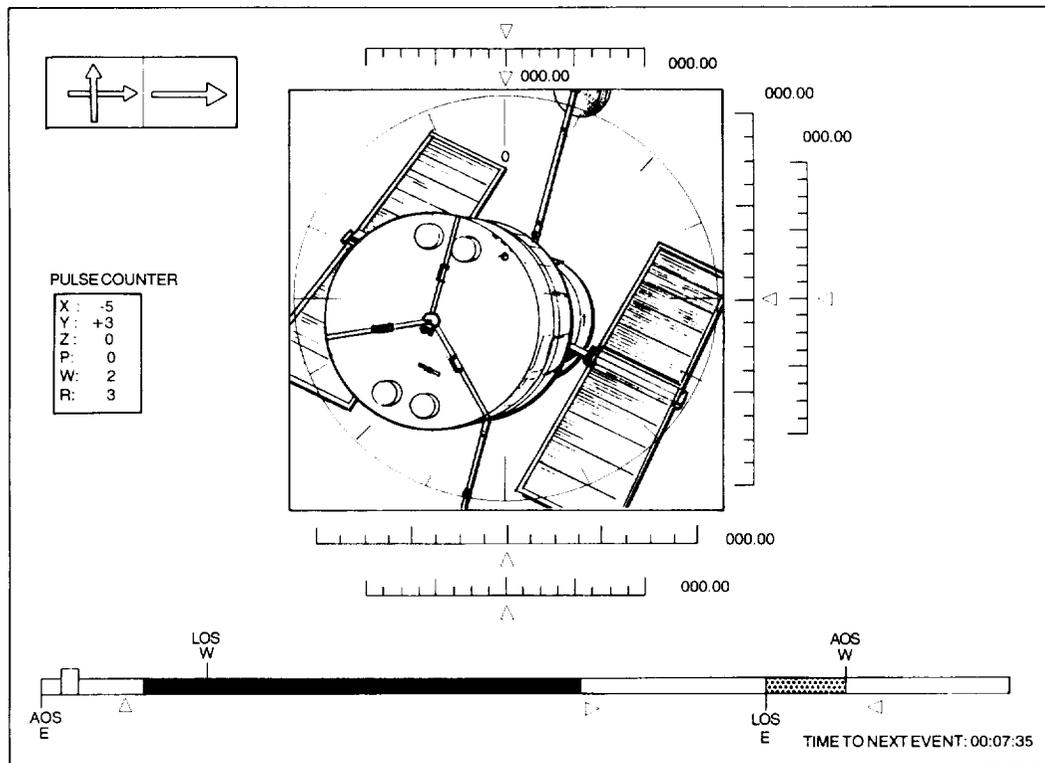


Figure 2. Pilot Overlays

provided and any questions were answered during the simulation. Pilots flew simulations during eclipse and docked with spinning targets. A history log was kept of each procedure and simulation for analysis. After each training procedure and simulation, pilots were debriefed. The total flight time exceeded 40 hours. Training time was limited to approximately 1 hour per pilot. The time for each run varied between 10 and 30 minutes.

The first review focused on two variables: text versus graphic displays and type of hand controller. Although these were the primary concerns, other feedback was also noted.

Review results were based on observations during flight simulations and pilot feedback gained from questionnaires and discussions. The evaluation focused primarily on the reasons for the success or failure to reach the simulation goal.

Initial Results

The review clearly showed a pilot preference for a hybrid of primarily graphic overlays mixed with some text. There were varying opinions expressed on the graphic versus text attitude direction indicator (ADI) format. In future reviews, pilots will select an ADI format from a palette of four displays. Digital range and range rate will be added to the enlarged analog radar display. The radar display will be enlarged to detect azimuth and elevation rates more easily.

Some of the overlays are placed directly on top of the video. These were difficult to see at times due to the underlying video color. Since the video contrast varies during orbit, there is a need to dynamically change the color of the overlays during simulation. One overlay color may be acceptable during one mission phase but not during another.

Pilots flew with targets spinning at 1.0 degree/second. It was apparent that the piloting techniques vary sufficiently to warrant another type of docking overlay. Specific aids for matching target spin rates and tracking rotating targets will be

included with the standard ranging information and docking allowance overlays.

Overall, the pilots liked the console ergonomics. Most preferred an adjustable tilt monitor. They were pleased with the monitor size and resolution. Pilots flew with both types of displays and hand controllers. One console had two 3-DOF hand controllers and the other had one 6-DOF controller with a different assortment and arrangement of switches. Switches varied in type, shape, color, and mounting. Pilots indicated that switch shape, size, or mounting did not aid in correct switch selection. Most pilots preferred flush-mounted switches.

Unverified piloting switch commands are indicated by flashing switches. The switch light changes color after the command has been verified or executed. This scheme worked well; most pilots did not prefer any other method.

Most pilots were trained to fly with two 3-DOF hand controllers and preferred to continue using them rather than the one 6-DOF controller.

CONCLUSION

It is evident that a full dynamic simulation is prerequisite to gaining useful data. Comments on an interface from an unrealistic simulator would have limited use. Likewise, trained pilots are needed to produce valid conclusions and avoid review comments which merely reflect unfamiliarity with the simulator, overlays, or piloting techniques.

The choice of pilot missions also influences the quality of gathered information. Carefully planned missions which stress pilot or OMV performance are most useful; during nominal missions, nearly all displays either work well or are never used.

By holding a series of pilot reviews and by building prototype displays, agreement will be reached on an acceptable pilot-machine interface. It is expected that having a community consensus on an OMV pilot-machine interface will prevent problems during the acceptance phase of the GCC project.